THE OBSERVATION OF EARTHQUAKES

A GUIDE FOR THE GENERAL OBSERVER

By H. O. Wood

This article is designed to put before the public in systematic, readable form such information about earthquakes as will enable ordinary observers to co-operate effectively with specially trained investigators in carrying through extensive earthquake surveys and inquiries. It is hoped that it will stimulate the widespread making of records of the behavior of earthquakes, especially throughout California and the neighboring region. It may be regarded simply as a brief manual for volunteer observers.

In the last two or three decades our knowledge of earthquakes has been greatly augmented. In large measure the invention and development of sensitive seismometric instruments has contributed to this, but, quite independently, important advances have also been made in our knowledge of earth shocks in relation to dynamical and surface geology and to works of engineering and construction.

Investigators employing delicate seismometric apparatus have discovered and demonstrated that all very strong earthquakes send perceptible wave movements all over the surface of the globe, and they find strong reasons for thinking that such motion is transmitted throughout the entire mass of the earth. These seismometers primarily are designed to discover and delineate the dynamical elements of earthquake motion—that is, the character, amount, direction and duration of the movements set up within the solid rock on which they are seated. In addition, they record the time of arrival at their stations of every phase of the wave motion; and, now, after accumulated experience, study of the seismogram permits a close estimate of the distance of the source of the disturbance, and, sometimes, an approximate notion of the direction from which it approaches. Such seismological laboratories work continually at securing information of this nature. But these as yet are very few in number, and they are distributed very irregularly over the earth, ordinarily separated by wide intervals. They are not in all cases located most advantageously. There are broad regions of the earth in which there are no such stations. Some of these districts are *often* visited by shocks. Already, nevertheless, synthesis of the investigations conducted in these laboratories has told us not merely the mode of the earth motion at such isolated localities, but how the energy is carried outward from its source, how its manifestations vary in character in different kinds of rock and at different distances from the place of origin, and how the waves traversing the earth space out at a great distance into three or more sorts running with different velocities. In this way these studies contribute matter of great value to our understanding of the constitution and physical state of the interior of the earth.

Also from these instrumental studies we learn how frequently great earthquakes occur and, in an approximate way, where they most often originate. An immediate large increase in the number of seismological stations, especially if their sites and equipment were chosen to the best advantage, would undoubtedly lead almost at once to significant advances in our knowledge of earth physics and thence, in secondary ways, to information of direct practical benefit. However, the primary purpose of such establishments is the increase of scientific knowledge. The results sought directly are not those the practical public deems of greatest importance. Direct benefit may come relatively slowly out of these investigations. Moreover it costs a great deal to build, equip, and maintain these laboratories. So it must be recognized, however regretfully, that a long time must elapse before an adequate network of stations can be established. Meantime many practical problems clamor for solution; so, while urging the building and equipping of seismological stations wherever practicable, recourse is necessary to a variety of other methods of earthquake investigation. Some of these auxiliary methods yield information of more practical value than the instrumental studies, and so, in themselves, are well worth prosecution.

To digress for a little: Instrumental seismology has demonstrated that each year recently, witnesses from ten to fifty strong earthquakes, shocks of the order that send measureable waves over the whole earth. Also Mallet, Milne and others, but especially Montessus de Ballore, have shown that these originate—with rare exceptions—in regions so related geographically that, when joined together, they form two narrow zones which in a rough way traverse the surface along great circles. These zones intersect at an angle of about 67 degrees. It is stated that more than ninety per cent of all earthquakes on record have emanated from origins within these belts. Hence they include nearly all the loci of seismic instability. Sketching roughly, one of these zones extends eastward from the Atlantic along the Alps through the Mediterranean basin, and along the Caucasus and the Himalaya. Possibly Jamaica and Central America lie in its course. The other zone borders the Malaysian Archipelago, skirts the islands along the eastern coast of Asia, including the Japanese group, follows the Aleutian chain, and sweeps along the mountainous western coast of North and South America.

Many thickly settled countries lie in or along the courses of these zones. Still, of the yearly quota of strong shocks in them, by far the greater part have origins under the sea. And a considerable majority of those originating beneath the firm land occur in places remote from the centers of civilization, and often in thinly settled localities. Sooner or later, however, the inhabited portions of these zones are shaken. In the last half-dozen years the blow has chanced to fall often and with terrible force upon thickly populated communities of high civilization: Central California, the environs of Valparaiso, Jamaica, Messina and its neighboring coasts. The total loss of life and property thus occasioned has been beyond precedent. This succession of disasters made deep impression on the present generation. Their lesson is obvious. Everywhere, and most especially in communities near the recognized seismic belts,—California being undoubtedly one of these regions,—the public should give generous support to the investigation of earthquake phenomena. And individuals in large numbers should aid specially trained seismologists in all practicable ways in the collecting of information about the occurrence and behavior of shocks.

From the point of view of human welfare the problems of first importance are these: *when* and *where* will strong shocks occur in future, and *what conditions,* which are subject to human control, tend to mitigate their diastrous consequences.

In the present state of knowledge we are, in general, unable even roughly to foretell the *time of occurrence* of shocks. There is hope of progress in this direction, but no immediate solution of the problem is expected.

The places where shocks will occur, however, and what the conditions are which may modify or control their behavior, we can already determine in advance with considerable accuracy. We know broadly the seismic belts of the world and where, in them, the districts are in which earthquakes have occurred most frequently and so are most likely to occur again. We know something, however little, about the geological causes of earthquakes and of their action under diverse geological and structural conditions. In order to determine more precisely where they are most likely to originate and to cause disaster, as well as the conditions which lessen or increase their dangers, we must carry on investigations in greater detail than has yet been done regarding the relations between the places of origin and the distribution of the perceptible effects of shocks; the relation between these effects and the geological character of the ground where they occur; how the character of structures affects the degree of the disaster,—in short, the inter-relationships of all these things, place of origin, phenomena, character of ground and of structures throughout the whole area in which the shock is felt perceptibly.

In regions where earthquakes occur frequently we need to correlate their places of origin, to compare their significant surface phenomena, to determine their distribution in time and space, all with relation to the geological structure of the district,—seeking thus to bring to light the immediate geological cause of the whole series of shocks and its mode of operation, whether this cause is acting permanently or only temporarily in the human sense, and whether the shocks come periodically or in a wholly sporadic way. For example, we already know several regions in which series of earthquakes have been caused by slip-faulting along recognized zones the courses of which are well marked by characteristic features in the land surface.

To effect such correlations adequately it is necessary to bring together complete and reliable news-accounts of the behavior of many shocks, great and small, from a great number of places in which each is felt,—in other words, to conduct a detailed seismic survey of as many earthquakes as possible. In doing this, people at large can render service of very great value. Indeed, without the co-operation of large numbers of observers little can be accomplished. Seismological stations, even if established in fair abundance, will not afford any detailed or precise knowledge of the size and shape of the area in which the shock is "felt," nor of the way in which its intensity varies over this area, nor of the character of the manifold attendant phenomena,—such as damage to structures or disturbances in the soil and rock. Such data as these can only be brought together through the co-operation of a large number of individuals living in different places who will note and report the facts which come *authenticallly* to their notice, and who will call the attention of trained seismologists to all permanent effects of the shocks. Besides its practical bearing, the results of such correlations have much scientific value, no less than the purely instrumental studies.

It is important to add at this point a warning that untrained observers should take great pains to report simply the facts observed. If they think it well to give explanations of the phenomena or theories to account for them, these should be kept distinct from the description or statement of the actual phenomena. With this qualification kept in mind, the great majority of persons whose occupation or temperament renders them observant are well qualified to aid in this work. All persons who feel any interest in earthquakes are urged to assist in collecting information about their occurrence and behavior, especially all who are situated in thinly settled or isolated localities. At best only a small percentage of the whole population will undertake such observation, so, in practice, there cannot well be too many volunteers even from the same locality. For, in general, earthquakes come at long intervals and endure only a few seconds. Even the keenest observer cannot compass all that is taking place about him. So the greater the number of persons who send in reports upon a given shock the more complete its description is sure to be. For the guidance of those who are willing to join in this work certain salient features of earthquake behavior are discussed in the following pages, with suggestions in regard to observing and recording earthquake phenomena.

THE OBSERVATION OF EARTHQUAKES

An earthquake is manifested at the earth's surface as a complex wave-motion due to vibratory movements of the rock particles, actuated by the elasticity of the rock material. These movements are set up by some sudden impulse or succession of impulses in the depths or by the sudden release of accumulated strain. Usually this earth motion is perceptible to the human senses over a region of considerable area, in which it produces a diversified range of phenomena. Immediately above the origin there is a confused and relatively violent motion with a noticeable up-and-down component. Near the margin of the affected region a nearly horizontal, gentle to-and-fro or swinging motion may be predominant. The character of the movement varies in this way with the angle of emergence of the wave trains, and thus influences the variations observed in the resulting phenomena. This variation in the character of the motion and its results helps to determine the place of origin of the shock. In the region near the origin the effects are numerous and varied, at the margin few and simple.

Serviceable records of earthquake phenomena should contain definite and detailed statements regarding:—

(*a*) The locality and whereabouts of the observer.

(*b*) The time of occurrence of the shock or shocks and of the distinguishable phases of each.

(*c*) Phenomena depending upon the energy of the shock, affording measures of its *intensity.* The transitory and permanent effects produced in nature and in artificial structures.

(*d*) The times of ocurrence, the duration and the character of the sounds accompanying the shocks, or preceding or following them.

(*e*) Sensations and emotions experienced,—dizziness, nausea, dread, etc.

(*f*) All unclassified effects.

(*a*) LOCALITY AND WHEREABOUTS OF THE OBSERVER.

Give the

State,

County,

City or Town,

Part of town (In order to identify closely the exact place of the observer at the time of the shock, give the street and number or the position of the place with reference to prominent landmarks).

Indoors or outdoors.

What floor or story.

How occupied at the moment of the shock.

In part such detailed information is necessary for accurate placement of the data contributed, in part it may be necessary for the critical interpretation of the phenomena noted, especially in the case of contradictory effects or apparent discrepancies among neighboring observers.

(*b*) THE TIME OF OCCURRENCE OF EACH SHOCK,

And so the number of them,—and of all the clearly distinguishable phases of each, should be given as closely as possible, for two principal reasons:

(1) To identify the shocks and their principal phases accurately, so that these may be compared with other similar observations of the same event.

(2) To aid in the solution of problems regarding the position, shape and depth of the focus (or foci in the case of a series of shocks), and in regard to the velocity of different sorts of earthquake waves, and to the surface factors which modify these.

To serve merely for identification of the shocks it is probably quite sufficient to give the time to the nearest minute or two, unless many shocks follow one another in quick succession.

Give the

Year,

Month,

Day,

Hour (do not neglect to specify whether a.m. or p.m.),

Minute, always as accurately as possible,

Second—*never,* unless it can be given *quite accurately.* But if attempt is made to give the time of the principal phases of the shocks, then it is necessary to state the time to the nearest second as accurately as possible.

For actual scientific service, all times should be accurately determined to the nearest second by a practised time observer—one trained to count seconds—using a timepiece whose error and rate is known or determined immediately afterward. The observer should ALWAYS *state whether he gives times accurately determined in this manner, or merely closely estimated, taking pains not to claim greater accuracy than actually pertains to the observation.*

The records of stopped clocks are interesting, particularly when the error of the clock was known and when details are given regarding the kind of clock, its placement with reference to the compass points, the nature of the base it rested on, etc.

With regard to these time observations it is suggested that telegraph and telephone operators, jewelers, railroad agents and others who are similarly associated closely with accurate time keeping, can contribute information of much interest and value.

The time of duration of each shock should be given as closely as possible, always with a statement as to whether the time given is an estimate or an accurate determination.

(*c*) THE INTENSITY OF THE SHOCK.

PHENOMENA DEPENDING UPON THE ENERGY OF THE SHOCK,—AFFORDING MEASURES OF ITS INTENSITY. THE TRANSITORY AND PERMANENT EFFECTS PRODUCED IN NATURE AND IN ARTIFICIAL STRUCTURES.

Most of the perceptible effects of earthquakes are approximately proportional to the energy of the shock at the place where they are manifested, and so serve to measure its intensity there. The observation of these effects demands a large share of attention.

When a shock occurs it is felt sensibly throughout a region roughly oval or elliptical in form for which the ratio between the longer direction and the shorter depends chiefly upon the depth, shape and character of the locus of origin of the disturbance. Further, the places in which its stronger effects are noted are found within a much smaller area near the center of the affected region, and this also is usually oval or elliptical in shape; but it is frequently more elongated than the whole region, being sometimes extremely long and narrow. Often there are more than one of these minor central areas where strong motion is manifested, and this points to a multiple origin for the shock; for the lines which separate districts in which high intensity prevails from the region less strongly shaken are determined broadly by the position of the origin or origins. In an intimate way such factors as the character of the ground at the surface make these bounding lines highly irregular and complex.

In general, intensity diminishes as the distance from the source of the shock increases; so that an accurate, detailed map of the variation in intensity determines the place of origin with considerable precision, permitting correlation of this with the geological structure of the region. Also, such a survey of the variation in intensity allows correlation of this with the character of the ground at the surface, with the nature and strength of the structures affected, etc., so enlightening us further upon the conditions which tend to lessen or increase disastrous results.

The information which auxiliary observers are asked to gather will yield a practical estimate of the intensity displayed in their localities. In spite of the conclusion reached later in this paper, namely, that auxiliary observers would better not attempt to use scales of intensity directly, it is probably best to explain how they have been asked to work hitherto.

The common practice has been to ask local observers to estimate the degree of intensity manifested in their own neighborhoods by comparing the effects and sensations noted by them with common sorts of earthquake phenomena which are used in framing the definitions of some *standard scale of intensity*. The Rossi-Forel intensity scale is the one which has been most commonly employed. In this scale ten grades or degrees of intensity are recognized, defined as follows:—

THE ROSSI-FOREL SCALE.

I. *Microseismic shock*: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. *Extremely feeble shock*: recorded by several seismographs of different kinds; felt by a small number of persons at rest.

III. *Very feeble shock*: felt by several persons at rest; strong enough for the direction or duration to be appreciable.

IV. *Feeble shock*: felt by persons in motion; disturbances of movable objects, doors, windows; cracking (? creaking) of ceilings.

V. *Shock of moderate intensity*: felt generally by everyone; disturbance of furniture, beds, etc.; ringing of some bells. (House bells are evidently meant, such as were in general use before the introduction of electric bells).

VI. *Fairly strong shock*: general awakening of those asleep; general ringing of bells (house bells); oscillation of chandeliers; stopping of (pendulum) clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. *Strong shock*: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. *Very strong shock*: fall of chimneys, cracks in the walls of buildings.

IX. *Extremely strong shock*: partial or total destruction of some buildings.

X. *Shock of extreme intensity*: ruins, disturbance of the strata, fissures in the ground, rock falls from mountains.

The foregoing version of the Rossi-Forel scale is that given by Dutton in his "Earthquakes." It is practically the original statement of the definitions. At different times various minor modifications of these have been made, but none of these changes have been incorporated here. This scale obviously is nothing more than a selection of the more commonly recurrent earthquake effects graded, roughly, according to the amount of energy required to produce them, and separated into groups so as to indicate a division of the intensity range into degrees. The division is made arbitrarily, for convenience simply. The scale has been used widely for a number of years, but it has never been considered as very satisfactory and at present it is losing favor. Other similar scales have been proposed to take its place, but none of these has thus far supplanted it in general use. Two in particular have, however, been adopted for local use: the Mercalli scale in Italy, and the Omori scale in Japan. These are discussed a little further on.

In use the Rossi-Forel scale is found to be arbitrary and indeterminate. Its scale divisions do not correspond, even approximately, to any regular or systematic division or grading of the range of intensity. Furthermore, each of its upper scale numbers covers very vaguely a large range of energy. The scale consequently does not afford nearly so minute a designation of the intensity as is frequently practicable or even necessary. Frequently workers investigating the distribution of intensity in the case of important shocks have rejected it and substituted in its place their own classifications of the local seismic phenomena.

Hence it would appear desirable for auxiliary observers to adopt some other scale, free from the more obvious defects of this one, or better yet, to follow some other plan for making record of the phenomena.

Let us next look at the Mercalli scale, which a little while ago was officially adopted in Italy in place of the Rossi-Forel scale. Dutton gives its definitions in English as follows:—

THE MERCALLI SCALE OF INTENSITY.

I. *Instrumental shock*: *i. e.*, noted by seismic instruments only.

II. *Very slight*: felt only by few persons in conditions of perfect quiet, especially on the upper floors of houses, or only by sensitive and nervous persons.

III. *Slight*: felt by several persons, but by few relatively to the number of inhabitants in a given place; said by them to have been "hardly felt," without causing any alarm, and in general, without their being sensible that it was an earthquake until it was known that others had felt it also.

IV. *Sensible, or moderate*: not felt generally, but felt by many persons indoors, though by few on the ground floor, without causing any alarm, but with shaking of fastenings, crystals, creaking of floors, and slight oscillations of suspended objects.

V. *Rather strong*: felt generally indoors, but by few outside, with waking of those asleep, with alarm of some persons, rattling of doors, ringing of house bells, rather large oscillations of suspended objects, stopping of (pendulum) clocks.

VI. *Strong*: felt by everyone indoors, and by many with alarm and flight into the open air; fall of objects in houses, fall of plaster, with some slight cracks in badly built houses.

VII. *Very strong*: felt with general alarm and flight from houses, sensible also out of doors; ringing of church bells, fall of chimney-pots and tiles; cracks in numerous buildings, but generally slight.

VIII. *Ruinous*: felt with great alarm, partial ruin of some houses, and frequent and considerable cracks in others; without loss of life, or with only a few cases of personal injury.

IX. *Disastrous*: with complete or nearly complete ruin of some houses and serious cracks in others rendering them uninhabitable; a few lives lost in different parts of populous places.

X. *Very disastrous*: with ruin of many buildings and great loss of life, cracks in the ground, landslips from mountains, etc.

While this scale is decidely an improvement over the Rossi-Forel scale in point of definiteness and in the matter of a more even division of the upper part of the intensity range, it is still merely an arbitrary grading of empirical effects divided unevenly, without scientific basis, into convenient groups. Moreover, some of the phenomena referred to in these definitions are peculiar to houses of European construction or to house furnishings now becoming obsolete. No tendency is observed to extend the use of this scale into other countries than Italy. Consequently we do not urge its employment here.

The scale now in use in Japan, devised by Professor F. Omori, is possessed of much merit. His own English version of it follows:—

THE OMORI "ABSOLUTE" SCALE OF DESTRUCTIVE EARTHQUAKES.

I. Maximum acceleration* 300 mm. per sec. per sec.—The motion is sufficiently strong that people generally run out of doors. Brick walls of bad construction are slightly cracked; plasters of some old *dozo* (godowns) shaken down; furniture overthrown; wooden houses so much shaken that cracking noises are produced; trees visibly shaken; waters in ponds rendered slightly turbid in consequence of the disturbance of the mud; pendulum clocks stopped; a few factory chimneys of very bad construction damaged.

II. Maximum acceleration 900 mm. per sec. per sec.—Walls in Japanese houses are cracked; old wooden houses thrown slightly out of the vertical; tombstones and stone lanterns of bad construction overturned, etc. In a few cases, changes are produced in hot springs and mineral waters. Ordinary factory chimneys are not damaged.

III. Maximum acceleration 1200 mm. per sec. per sec.—About one factory chimney in every four is damaged; brick houses of bad construction partially or totally destroyed; a few old wooden dwelling houses and warehouses totally destroyed; wooden bridges slightly damaged; some tombstones and stone lanterns overturned; *shoji* (Japanese paper-covered sliding doors) broken; roof-tiles of wooden houses disturbed; some rock fragments thrown down from mountain sides.

IV. Maximum acceleration 2000 mm. per sec. per sec.—All factory chimneys are broken; most of the ordinary brick buildings partially or totally destroyed; some wooden houses totally destroyed; wooden sliding doors and *shoji* mostly thrown out of the grooves; cracks two or three inches in width produced in low and soft grounds; embankments slightly damaged here and there; wooden bridges partially destroyed; ordinary stone lanterns overturned.

V. Maximum acceleration 2500 mm. per sec. per sec.—All ordinary brick houses are very severely damaged; about three per cent of the wooden houses totally destroyed; a few *tera,* or Buddhist temples, thrown down; embankments severely damaged; railway lines slightly curved or contorted; ordinary tombstones overturned; *ishigaki,* or masonry walls, damaged here and there; cracks one or two feet in

*The term acceleration is explained below.

width produced along river banks; waters in rivers and ditches thrown over the banks; wells mostly affected with changes in their waters; landslips produced.

VI. Maximum acceleration 4000 mm. per sec. per sec.—Most of the *tera*, or Buddhist temples, are thrown down; fifty to eighty per cent of the wooden houses totally destroyed; embankments shattered almost to pieces; roads made through paddy fields so much cracked and depressed as to stop the passage of wagons and horses; railway lines very much contorted; large iron bridges destroyed; wooden bridges partially or totally damaged; tombstones of stable construction overturned; cracks a few feet in width formed in the ground, accompanied sometimes by the ejection of water and sand; earthenware buried in the ground mostly broken; low grounds, such as paddy fields, very greatly convulsed, both horizontally and vertically, sometimes causing trees and vegetables (vegetation) to die; numerous landslips produced.

VII. Maximum acceleration much above 4000 mm. per sec. per sec.—All buildings, except a very few wooden houses, are totally destroyed; some houses, gates, etc., projected one to three feet; remarkable landslips produced, accompanied by faults and shears of the ground.

In the above scale of the seismic intensity the earthquake motion has been assumed to be entirely horizontal. This supposition would not, except in places very near to the epicentre, cause sensible errors in the result.

It is obvious at once that this scale is much more definite and serviceable than either of the two previously given. It subdivides the upper range of intensity much more minutely, obviating to a considerable degree one of the more serious defects of the other scales. Moreover, since the scale is not designed to grade weak shocks, it tacitly recognizes a fact of importance, namely, that earthquakes of great power ought to be judged by different scales of intensity than such as should be used for grading weak shocks. This fact has never anywhere received sufficient emphasis.

Further it will be noted that the Omori scale is designated an "absolute" scale. By this is meant simply that *the dynamical equivalent of the range of intensity for each grade of the scale* has been determined with considerable accuracy. In the language of dynamics the *intensity* of an earthquake is considered to be proportional to the *acceleration** of the vibratory movements of the earth particles.

In Dutton's "Earthquakes" the intensity is given by the formula

$$I = \frac{2\pi^2 a^2 VD}{t^2},$$

I = intensity,
a = amplitude,
t = period of vibration (of the particle)
V = velocity of wave transmission,
D = density of the medium,

where the acceleration, α, is expressed thus:

$$\alpha = \frac{4\pi^2 a}{t^2};$$

and hence $$I = \frac{4\pi^2 a}{t^2} \cdot a \frac{VD}{2},$$

$$= \alpha \,.\, a \,.\, k, \quad \frac{VD}{2} = k = \text{constant},$$

whence it is clear that the intensity increases or decreases when the acceleration increases or decreases; but, if the acceleration chances to reach the same value approximately in two or more cases, then the intensity varies as the amplitude. So the intensity is affected both by the rate of change of speed and by the amount of motion.

By means of experiments conducted with a shaking table, Professor Omori determined with sufficient accuracy the values of the acceleration required to produce such actual effects as he has employed in defining the grades of his scale. Thus it comes by its designation, an absolute scale. That it is such at one and the same time urges its employment for measuring intensity, and militates against such use

*By acceleration is meant the rate of change of speed in the motion of the earth particles. It will be obvious after a little thought that it is not either a rapid motion of the earth particles nor a slow motion which produces the oversetting of objects and the wrecking of structures on the earth's surface—because, for example, there is no effect of this sort in a rapidly but uniformly moving train nor in a vehicle moving with a slow, uniform speed—but it is a sudden, rapid change from a very slow speed or from absolute rest at one instant to a relatively rapid velocity at the instant following, or vice versa. It is *change of speed,* bringing inertia into action, which produces earthquake damage; and the *rate of change of speed* is the acceleration. This usually is measured in millimeters per second per second, *e. g.,* a velocity of x mm. in a given second is either increased or decreased by y mm. in the following second.

of it here. On the ground that it would add definiteness to or yield measured values of intensity its use is greatly to be desired: but when used, the acceleration values determined in this way should be checked and verified by comparison with the accurate measures of seismometric instruments at numerous places. As yet seismological stations are too few in number in the California region to afford sufficient comparisons. Moreover, we lack experimental studies made to determine what acceleration values are required to produce the effects observed in American structures, for these differ widely from Japanese types. In view of this, its very accuracy in delineation of the grades stands as a bar to the sound, practical use of this scale in this region.

Still another intensity scale deserves mention because it contemplates a division of the range of intensity into grades in a regular way. This scale was introduced by Cancani before the Second International Seismological Conference held at Strassburg in 1904.

THE CANCANI DYNAMICAL SCALE OF INTENSITY.

I.	Instrumental	0.0	2.5 mm. per sec. per sec.
II.	Very light	2.5	5.0 mm. per sec. per sec.
III.	Light	5.0	10.0 mm. per sec. per sec.
IV.	Sensible, mediocre	10.0	25.0 mm. per sec. per sec.
V.	Rather strong	25.0	50.0 mm. per sec. per sec.
VI.	Strong	50.0	100.0 mm. per sec. per sec.
VII.	Very strong	100.0	250.0 mm. per sec. per sec.
VIII.	Ruinous	250.0	500.0 mm. per sec. per sec.
IX.	Disastrous	500.0	1000.0 mm. per sec. per sec.
X.	Very disastrous	1000.0	2500.0 mm. per sec. per sec.
XI.	Catastrophic	2500.0	5000.0 mm. per sec. per sec.
XII.	Great catastrophe	5000.0	10000.0 mm. per sec. per sec.

Cancani made no endeavor to define the grades of this scale in terms of equivalent destructive effects. Indeed, until our knowledge is much more complete in regard to the values of acceleration and amplitude, and their interrelationships, which must be reached in order to produce the more important effects which could be used in giving practical definition to these grades, it would be unscientific to specify ordinary equivalents for these grades. So despite its positive merit it is not now possible for observers, whether trained or not, to use this scale. It can be utilized only where seismometric records of some sort are available.

The foregoing comprise the more important scales for measuring earthquake intensity. None of them can be recommended for the use of untrained auxiliary observers. Everyone undertaking to assist in the observation of earthquake phenomena ought to know about them and how they are employed. But there is grave doubt whether anyone untrained in their critical interpretation should try to use such scales directly. Charles Davison states the requisites of a suitable intensity scale as follows:—

(1) The degrees of the scale should depend as far as possible on the mechanical effects of the shock and not on personal impressions, which may vary in different countries or with different observers in the same country, or with the same observers at different times.

(2) Each degree of the scale should depend on one test only, unless the exact equivalents of the two tests have been determined previously.

(3) The number and closeness of the degrees should be such that the scale is equally serviceable for weak, for moderately strong, and for destructive earthquakes. (The present writer dissents from this opinion, though recognizing the disadvantages of two or more distinct scales.)

No scale yet proposed satisfies all these conditions. Probably any scale whatever would be unsuited to *general* use. The observer who has received no special training ought not to apply any such yardstick to his observations. This opinion is fairly general among geologists who have been directly concerned with the investigation of earthquake phenomena. It assuredly was the opinion of the majority of those who studied the 1906 earthquake in California. At that time this was the unconscious verdict of the public also. The great majority of persons who then contributed observations, sent in of their own accord reports of what they saw and experienced, instead of estimates of the grade of intensity, thus tacitly recognizing the impracticability of their utilizing the Rossi-Forel scale, which they had been asked to employ.

Nevertheless, if auxiliary observers are asked to aid in making record of the behavior of earthquakes, without making use of intensity scales, then it is necessary to acquaint them with the sort of phenomena which have proved useful in investigating the variation of energy in regions affected by earthquake shocks. In undertaking to describe such effects and to discuss them, we are confronted at once with the need for discriminating between the action of weak and moderately strong shocks on the one hand, and diastrous shocks on the other hand. It seems to the writer and those he has advised with that these ought not to be measured in the same way.

Knowledge of the areal variation in intensity is nevertheless equally valuable in both cases. For since the region of maximum intensity in the case of weak shocks is small and fairly well marked, it serves to indicate very closely the position of the origin of the shock—and in seismically unstable regions weak shocks are considered to be minor disturbances emanating frequently from the zones within which disastrous shocks originate at longer intervals. Careful survey of the weak shocks should discover to us, then, the chief zones of causation and, consequently, the places of greatest danger from earthquakes.

On the other hand the region of high intensity in the case of destructive shocks is large, vaguely and irregularly delimited, and in detail controlled more closely by the character of the rock or soil at the surface than by proximity (in a narrow view) to the source. Consequently it often does not indicate very definitely the place of origin of the shock. It does, however, afford invaluable information as to the influence of various surface conditions and materials in modifying the action of the shaking,—and such information, obviously, is of great practical value.

None the less, a small area in the region of high intensity of a weak shock and a similar area at considerable distance from the epicentral region of a cataclysmic shock, may each receive about the same amount of energy in a given time, and so, in some respects, display the same degree of intensity. But in the first case the wave trains emerge at a relatively high angle, with a much lower angle in the second case; also there is a more or less marked difference in the period and amplitude of the wave movements in the two cases, due to initial differences in the amount and character of the motion and to the transformation it undergoes in its outward propagation through the rock,—a transformation which varies with the distance traversed. In consequence it is to be expected that the effects produced in the two cases will differ in character though representing equivalent energy. This is actually found to be the case, but though implicitly recognized in sundry ways, emphasis has never been laid on this point by investigators of seismic intensity. This difference makes it practically necessary to judge strong earthquakes and weak ones by different criteria. Of course there is no logical separation boundary between weak and strong shocks, and occasional shocks occur which belong to the border zone between. It is rare, however, that a shock cannot be placed without hesitation in one group or the other.

HIGH INTENSITY.

Phenomena Found in the Meizoseismal Area of Great Shocks.

The Hurling of Objects into the Air.

Probably none of the phenomena noted at the time of an earthquake denotes a higher degree of intensity than this, the hurling of heavy objects into the air free and clear of their resting places. For to accomplish this the *upward acceleration* of the earth motion must attain a value exceeding considerably that of gravity in order to overcome the action of gravity, the inertia and the adhesion. Such projection of bodies into the air has been observed only very rarely and then only in earthquakes of tremendous power. Indeed for a long time critical scientific men questioned the reality of such action. Great earthquakes come at long intervals, and our accounts of them, until recent decades, were usually meagre, unscientific, and plainly wrong in some matters. Still in the accounts of nearly all of the very strong earthquakes this throwing upward of loose objects has found mention. In the great earthquake which visited Calabria in 1783 it was reported that "paving stones were thrown up from the surface of the ground for several yards." Our reports upon this earthquake are probably more complete and reliable than in any case prior to the modern scientific era.

Von Humboldt, writing in his Kosmos of the famous Riobamba earthquake of February 4, 1797, mentions such action,—along with other phenomena, all indicating such extraordinary violence that his account has been considered very questionable, especially so inasmuch as he did not himself observe the facts but merely gathered his information from local sources. For example he states without any critical comment that " . . . the bodies of many of the inhabitants were found to have been hurled to Cullca, a hill several hundred feet in height and on the opposite side of the river Lican."

Such violence passes belief, becoming even more incredible when subjected to analysis than when viewed in a common-sense way. Moreover, Humboldt's descriptions of other intensity phenomena on this occasion are very difficult to accept, as we shall see.

In very recent years, however, it has been *demonstrated* that objects sometimes are thrown forcibly into the air in great earthquakes. The testimony of the great earthquake in Assam, British India, June 12, 1897, leaves no room for doubt on this point. This shock was investigated in the field by officers of the Geological Survey of India under the direction of Professor R. D. Oldham, then Superintendent of this Bureau.

Near Shillong in the region of the origin of this shock loose stones were seen, by English observers, to be tossed in the air "like peas on a drum." In the course of his investigations, Professor Oldham himself saw where, on the grassy slopes of the Khasi hills, weathered boulders from one to three feet in diameter, roughly spherical in form, had been flung upwards "driven from their seats and hurled through the air, leaving a sharply cut mould in the soil, slightly broken down on the side toward which the block was projected." In level spots such boulders were flung out of place from two to four feet (to one side). "One long splinter of granite, three feet long and of triangular section with sides of about twelve, ten and nine inches . . . was thrown eight and a half feet from its original position." This was the greatest effect of this sort which came under observation. Still, some of the "small Khasia monoliths (rough stone posts about six feet high) were shot upwards out of the ground," and one of these traveled six and a half feet through the air before its lower end again touched ground.

In this earthquake this tossing of objects into the air was noted throughout a considerable area, in which great energy manifested itself in many ways.

Since the objects adhered to the soil, especially boulders sunk in sod moulds, Oldham concluded that the upward acceleration of this shock in its meizoseismal region was not merely greater than that of gravity, but possibly four or five times as great. He explains that very large, heavy bodies are not thrown upward at such times because of their great inertia and the lost motion due to the compacting of the loose earth beneath them. For very small objects which adhere strongly to the soil, the momentum communicated to them by the shock is not sufficient to overcome the adhesion.

Certain of the effects produced during earthquakes may appear more striking and more terrible than these, but none attest a greater intensity *measured* in terms of acceleration. Of course it must be kept clearly in mind that we are speaking of *things thrown upward into the air*—not simply rolled about or made to bound into the air while rolling down hill. For in this Assam earthquake, in the vicinity of the Chedrang fault, boulders ten to twenty feet in diameter, even up to thirty feet in some instances, were moved about with rolling and bounding.

Distortion of the Land Surface: Disturbance of Lines of Sight and Levels.

Slow movements in the earth's crust producing elastic strain, give rise to earthquakes, with release of this strain and compensatory sudden movements. These sudden movements must in many cases distort or change the plan of surface areas within the disturbed region. Indeed, the amount of change suddenly produced in certain great shocks has been sufficient to perceive easily, without the aid of refined measurements.

Von Humboldt's account of the Riobamba earthquake furnishes graphic pictures—unfortunately of doubtful reliability. "In the great earthquake of Riobamba in the province of Quito (February 4, 1797), [and in that of Calabria (February 5 and March 28, 1783)] walls were changed in direction without being overthrown, straight and parallel rows of trees were inflected, and in fields having two sorts of cultivation, one crop even took the place before occupied by the other; the latter phenomenon shewing either a movement of translation. or a mutual penetration of different portions of the ground. When making a plan of the ruined city of Riobamba, I was shewn a place where the whole furniture of one house had been found under the remains of another; *the earth had evidently moved like a fluid in streams and currents, of which we must assume that the direction was first downward, then horizontal, and lastly upward.* Disputes concerning the ownership of objects which had *thus been carried to distances of many hundred yards* were decided by the Audiencia, or Court of Justice." The phrases of this quotation italicized by the present writer probably find no acceptance among scientific men in our day.

Again, however, the great Indian earthquake comes to the rescue with definite facts. Captain A. A. Howell, Deputy Commissioner of the Garo Hills, makes the following statement in his report: "It is generally stated that some hills have sunk bodily many feet, while others have risen. In the case of two hills between Tura and Rowmari, this assertion is corroborated by the signalers of the Military Police, who have been constantly practicing with the heliograph from these two places."

Again, in Oldham's own report: " . . . at Mao-phlang on the road from Shillong to Cherrapunji, where Mr. Evans informed me that, after the earthquake, he noticed a considerable change in the appearance of the hills to the west. In part, the statements were general and might be attributed to imagination or defective memory, but two definite facts can hardly be explained in this manner.

"Beyond Mao-phlang is another mission settlement at Mairang, and on such occasions as the missionary there visited Mao-phlang a look-out for the arrival of the party was naturally kept by Mr. and Mrs. Evans. Before the earthquake, I was informed that only a short stretch of the road was visible, where it rounded a spur at about three miles off: the crest of an intervening ridge hiding the road before it came out round the next spur. Now a much longer stretch of the road is visible, and it can be seen rounding the next spur, where I was positively informed the road could not be seen before the earthquake.

"The second fact is that a few days after the great earthquake Mr. Evans took a piece of board and nailed it to a stout post in such a position that its upper edge was sighted on to the crest of a ridge about one and a half miles to the west. When I saw it, at the end of December, six months after the earthquake, the top edge of this board was no longer pointed to the crest of this ridge, but to some way down its slope. The angle subtended between the point where the edge of the board then pointed to, and the crest of the hill was about 1°, as determined by an Abney's level, and the change might be due to a displacement of the post, though there was no appearance of such. Apart from this, Mr. Evans informed me that when the board was put up he could only just see the top of the next ridge, beyond that on which the board was sighted; now a considerable stretch of this can be seen, and according to Mr. Evans much more than was visible soon after the earthquake." (It should be stated that there were thousands of aftershocks, many quite strong, which probably brought about changes subsequent to the main shock.)

"The next place where similar evidence was obtained was on the road through the Garo Hills to Damra, where it crosses the high ground north of Cheran and just before descending into the valley of the Bangshi. Here I was informed by the mouzadar accompanying me that before the earthquake it was only just possible to see the Brahmaputra over an intervening hill, while now the whole width of the river was visible."

A re-survey of triangles previously determined in this region showed relative displacements in altitude and position quite large enough to permit such observations as were noted above.

Even in the California shock of 1906 the surface underwent distortion on the large scale but, except in the immediate vicinity of the fault, an accurate survey was required to detect the changes. One paragraph of the report on the re-survey of the California triangulation is quite certainly of general interest and deserves to be quoted here.

"The permanent displacements and distortions which took place at the time of the earthquake of April 18, 1906, may be pictured by imagining a series of perfect squares drawn on the surface of the ground before the earthquake, with their sides parallel and perpendicular to the fault. At the time of the earthquake every square to the eastward of the fault moved bodily in a southerly direction parallel to the fault, the squares more distant from the fault moving less than those near to it. All sides of squares parallel to the fault remained straight lines, unchanged in length and direction. For the squares to the eastward, the sides perpendicular to the fault became curved lines concave to the southward and changed in direction as a whole by rotation in a counter-clockwise direction, the change being 52″ or more for squares near the fault, and less for more remote squares.

"The angles of the squares all took new values differing from 90° by quantities ranging from more than 52″ to zero. The squares to the westward of the fault, were moved bodily in a northerly direction parallel to the fault, their sides parallel to the fault remaining straight and unchanged in length and direction. Their sides perpendicular to the fault became curved lines concave to the northward and each changed in direction by rotation in a counter-clockwise direction, the change being more than 31″ for squares near the fault and less for more remote squares. The displacement of squares near the fault was twice as great for squares on the western side as for squares on the eastern, but the distortion was slightly less for squares on the western side than for squares on the eastern side. The appreciable displacements extended back much farther from the fault on the western side than on the eastern side.

"It is not probable that the actual displacements and distortions were perfectly regular as indicated in the word picture of the preceding paragraph, but the apparent departures from this perfectly regular ideal, of the displacements and distortions detected by the triangulation, are nearly all so small as to be possibly due to errors of observation."

So it is proved conclusively that the earth's surface suffers permanent distortion within the meizoseismal area of earthquakes of great power, and the foregoing quotations convey a good idea of the nature of the changes produced. However, such effects have rarely been observed directly, possibly because they seldom result, and since the re-survey of a system of triangulation is not undertaken unless the necessity for it is clearly perceived, it is not unlikely that these surface deformations have often been overlooked. For it is frequently noticed that alluvial lands in regions of high intensity are compressed, with the bending and shortening of lines on the surface as demonstrated by the crumpling of rigid linear structures such as railroad lines, bridge spans, roads and the like. Some amount of such compression must result from the consolidation of the relatively loose alluvium in consequence of the shaking it receives, but this may well be accompanied by a warping of the solid rock augmenting the compression. In any event, whatever the mechanism, effects of this kind, as well as the phenomena which indubitably show distortion of the crust, are sure criteria of great intensity and have much practical and scientific interest.

Surface Fault Phenomena—Fault Traces, Scarps and Rock Fissures.

Reference has already been made to the opinion that most earthquakes result from jars accompanying slipping in the rocks when blocks of the earth's crust undergo movement relative to their adjoining parts. This view is still only a hypothesis, for it is very seldom that such relative movements among parts of the crust become visible at the surface in connection with an earthquake. Ordinarily such displacements effected in the depths are considered to be "taken up" by the overlying materials, so that the offsets die out before actually intersecting the surface. However, it has frequently happened in connection with great earthquakes that these movements of displacement extend to the surface, thus demonstrating their causal association with the shock. Such ruptures commonly take the form of approximately rectilinear breaks at the surface, with the ground on opposite sides displaced or offset vertically, and often horizontally too, producing a fresh step or embankment in places where the surface previously was even and uninterrupted. Such a line or zone of intersection of fault movement with the surface of the earth has been designated the "trace" of the fault. When vertical displacement characterizes it the feature is called a "scarp." Such scarps may rise from a few inches to several feet in height; twenty to thirty feet has several times been noted, but as yet fresh slips, accompanying earthquakes, greater than fifty feet in height have not been observed. From its height at the maximum point these scarps fall off passing along the course, sometimes falling and rising with several intervening maxima and minima, until finally the displacement at the surface dies out altogether. It is not uncommon when the surface is thus broken for more than one of these scarps to be formed. In the 1872 earthquake in Inyo County, California, several such steps were formed, arranged *en echelon;* that is, with one beginning a little to one side of the point where another begins to die out.

More rarely, as in the case of the 1906 earthquake in California, the rupture takes the form of a series of long cracks or rude, furrow-like rips or jagged tears in the earth and sod, which extend for great distances along a straight course. Then these are usually found to follow long valley- or trough-like features in which are found peculiar developments of the forms of the land surface. Marked lateral displacements of fences, roads, and other horizontal linear features running athwart the course of the rupture, may be produced without any consistent or noteworthy vertical displacements accompanying them. There is much reason to think that "traces" of this variety have been developed during several of the greater shocks which have visited the Coast Range province of California.

When they occur both sorts of trace tend to traverse the region characterized by high intensity along a course roughly parallel to its longer direction, thus marking the major axis of this area. All shocks which are accompanied by such surface ruptures manifest very high intensity in their neighborhood.

In most great shocks, fissures or deep cracks are produced in the firm rock. These often are of considerable size and extent. They are different from fault traces in that they are not marked by definite or regular displacements, either horizontal or vertical. Also they may curve sharply (as well as follow straight courses), and their direction is quite haphazard, so that they intersect irregularly with each other.

When these occur in firm rock they denote extremely high intensity; when in loose ground they are less significant, although weak earthquakes never produce them. Unless they are examined with care it is impossible to discriminate between cracks and fissures of this sort and those developed along fault scarps and traces. Since these two sorts of surface rupture have very different significance, their differentiation is of fundamental importance; and marked phenomena of this kind should always be brought to the attention of trained investigators.

Surface Changes in Loose Earth.

The agitation of loose surface materials, regolith, alluvium or artificial filling, by the vibratory movement of an earthquake results in bringing the particles into closer contact, and these changes of position, of course, take place under the action of gravity, so that the deposits settle to lower levels, and sometimes, especially when soaked with water, behave as a viscous fluid and flow. Hence ordinary *landslide movements* are universal sequels to strong earthquakes in soil-coated hill countries.

Ordinary landslides or *earth slumps* occur on maturely developed hill slopes, and their movement is much accelerated by a strong earthquake, both at the instant of occurrence and again later on when the rains of the wet season have re-saturated the agitated material. In California these earth slumps are very common, and are marked by recurrent movement, when wet up by the winter rains, interspersed with periods of arrest in the long dry season.

Where there are substrata highly charged with water, the compressive action of a strong earthquake forces this out through an orifice at the surface, producing an *earth flow*,— a stream of fluid mud rushing suddenly through a considerable distance.

On steep cliff sides and canyon slopes loose, *dry* earth, resting on slopes near its angle of repose or standing up by feeble adhesion of its particles in a condition of relative instability, is shaken down copiously in a strong earthquake, producing *earth avalanches*.

"Besides these three types of landslide, another ought perhaps to be recognized. This is the form of superficial earth movement which occurred in consequence of the earthquake shock on the alluvial bottom-lands of many streams. It may appropriately be designated an *earth-lurch*. It varies from the opening of a mere crack, with a slight movement of the ground on one or both sides, to a violent and complicated deformation of the surface, usually accompanied by cracks and open fissures parallel to the trend of the neighboring stream trench.

These cracks and fissures cut the ground up into strips or prisms which lurch toward the stream trench, or, it may be, toward an abandoned slough, the lurch usually being accompanied by a rotation of the prism. They are distinguished from all other forms of landslides by occurring on perfectly flat ground and by the fact that they are apparently referable directly and solely to the horizontal jerk of the earth movement during the earthquake shock."

While the motion of the earthquake is in progress, waves or billows, appearing like those we see in water, are sometimes seen running with great rapidity over the land surface. Observations which may help to determine the wave-length, amplitude and period of these surface waves are greatly desired. For, so far, we have only the rudest estimates of these quantities. These probably vary in different kinds of soil, and may depend in part on the amount of water present in it. After the shock has passed, the surface sometimes remains warped into wave-forms or earth-billows. It is not definitely known whether these result from the arrest and solidifying of these running waves, after the forced vibration ceases, on account of the viscosity of the medium, or from the generation and solidification of stationary waves, showing nodes and antinodes, within partially closed, shallow, basin-like areas.

All these permanent movements of the loose earth are characteristic of high intensity.

Effects on Underground Water.

Ground water plays a very important part in all these disturbances of the loose deposits, faciliating their deformation and displacement. In consequence, interruption or change in the movement of underground water is a most common accompaniment of great shocks. This action, while most commonly observed in the neighborhood of the origin of the earthquake, is not lacking at considerable distances, often well beyond the limits of the meizoseismal region. Weak shocks scarcely ever produce effects of this kind, even in the region of their greatest energy. So disturbances of ground water, when general, are indications of strong shocks.

Springs are dried up or dimished in flow in some instances; in others newly generated or increased in flow. Their waters are frequently changed in character: rendered turbid or hot or saline. Such changes are often temporary, but occasionally they persist.

The shock may squeeze water out from wet alluvium as from a sponge, inundating considerable areas, now and then converting them into swamps. Or small lakes or swampy tracts may be drained by the opening up of new subterranean flow lines. Temporary or permanent changes in the volume of flow of streams at the surface may be brought about by such derangements in the movements of the ground waters.

Water is discharged under pressure from surface orifices, producing miniature geysers which play during the shock and leave, after their spouting has ceased, shallow basins or inverted cones, from a few feet to a few inches in diameter, lined with sand or mud. These somewhat resemble volcanic craters in miniature, and for this reason they have been designated *craterlets*. These are often arranged along a system of fissures. They are found only within the area of high intensity.

Effects in Forests.

Forests within the meizoseismal areas of disastrous earthquakes often show trees broken—snapped off at the crown like chimney tops—or overturned and uprooted. They are sometimes caused to die as the result of disturbances in the ground their roots traverse. Extreme energy must be manifested to produce phenomena of this sort.

Waves Along Sea Coasts.

Though not universal, it is usual when great earthquakes have origin near coasts, particularly when under the sea near land, that the sea is greatly disturbed and waves of greater or less magnitude are noted at the shore. Sometimes the sea retreats and then returns rising higher than normal; sometimes it begins by rising suddenly upon the strand. In either case, when it is large it surges and resurges several times, gradually diminishing in energy. These waves vary from magnitudes just perceptible up to heights of thirty, forty and possibly even fifty feet or more. Consequently they are often a most disastrous factor of the shock. Their occurrence has a bearing on the probable character of the earth movement which produces a shock, and they should be noted carefully.

Damage in Buildings and Structural Works.

So numerous and diverse in character are the effects produced in structures located in the region visited by an earthquake, that any description or classification of them approaching completeness is out of the question. They range in degree from the complete demolition of strong works of construction, in the places of maximum energy of the greatest earthquakes, down to scarcely perceptible cracks in fragile materials such as plaster, or sensitive structures such as tall, slender chimneys, located far from the origin of a strong shock, or possibly developed in the meizoseismal district of a shock of moderate power. In the matter of structural damage the effects produced are so multitudinous and so various in nature that no characteristic differences of quality are observed among them, speaking broadly, in shocks of different strength,—the difference in the damage indicating differences of degree only. In some instances peculiar effects are produced which require for their explanation the emergence of waves of considerable energy at low angles; and therefore, though manifesting only moderate intensity, these indicate a great shock at a distant origin.

All phenomena which can be grouped under the term *structural damage* are due to sudden distortions in the relatively rigid structures, caused by the irregular undulatory disturbance of their rock or ground foundation seats, coupled with their inertia; or to secondary distortions, such as result from the falling of buildings from their underpinning, or to wave motions proper to the structures themselves set up in them by the disturbances of their seats—a transformation of the earth-motion by the structure, occasionally gaining thus in power to destroy.

Under structural disturbances it is convenient to include all movements of furnishings or fittings or of any loose objects, including fluids, which occupy the structures.

A complete study of phenomena of this kind not only serves to fix with much precision the place of origin of the shock and the surface conditions which modify the intensity it manifests, but it serves also to enlighten us regarding better and worse methods in construction with regard to safety from earthquakes. Consequently it is of the greatest importance that all such effects be described completely—as briefly as is consistent with clearness and detail.

LOW INTENSITY.

Weak Effects of Strong Shocks.

Passing outward from the center of the shaken region the phenomena perceptible by the senses and those which produce permanent changes in natural objects and structures grow less in number and in degree, until finally we cross a shadowy boundary beyond which no manifestations of the shock are perceptible except by the aid of sensitive seismoscopes. In great shocks, between this outer boundary and an inner isoseismal along which the vibrations are clearly but feebly *felt* as such, there is an irregular belt where the shock makes itself known by disturbances in structures and natural features whose properties make them *natural seismoscopes*. Such effects have not as yet been noted when weak shocks occur.

Occasionally a gentle swaying motion, quite unlike the sensation of lively vibration usually produced by an earthquake, is experienced, and this is often accompanied by nausea and dizziness. Sometimes nausea and dizziness are perceived without cognizance of the swaying. To be significant these sensations must be felt fairly generally, and must coincide with the shock in time of occurrence, since they are likely to be occasioned by other causes. The more rapid vibratory movements also may occasion nausea.

At great distance from the focus of an earthquake gentle swaying is perceived in the upper stories of tall structures, a slow swing whose amplitude sometimes becomes alarming. Such slow, gentle heaving was felt in Massachusetts and in Michigan at the time of the Charleston earthquake in 1886. Such buildings then behave like inverted pendulums especially sensitive to wave-movements of long period.

Movements of pendulum-like structures of all sorts, normal, horizontal and inverted, are characteristic of this outer zone of weak intensity. Doors swing slowly to and fro in calm air. Trees wave. Chandeliers, lamp-cords and similar suspended objects oscillate: these of course swing more rapidly or slowly according to their length. Rocking-chairs are set in motion. Tall vases sway and totter. In the absence of any sensation of motion the balls on billiard tables have been observed to take erratic courses at the time of strong earthquakes.

Standing water in small vessels or tanks, or at rest in small lakes, ponds or ditches, suffers disturbance of level and oscillates slowly in its basin. In 1897 at the time of the great Indian earthquake a cistern of water in the basement of the geodynamic observatory at Casamicciola on the island of Ischia near Naples was measurably disturbed. The great Lisbon earthquake disturbed the level surface of lakes in many parts of Europe, and possibly even in Iceland and eastern North America. Forel has observed numerous periodic disturbances of level in the Swiss lakes which he has attributed to earthquakes. In 1906 similar action was noticed on April 18th in parts of California remote from the fault-origin of that earthquake, and even in western Nevada.

LOW INTENSITY.

The Effects of Weak Shocks.

The intensity phenomena of weak earthquakes can be dismissed in few words. They develop no effects of any kind which require great energy for their production, even in the epicentral tract. The weak effects which they do cause differ from those characteristic of strong shocks just discussed above—apparently on account of the mechanism of their causation. Weak shocks have so little initial power that their waves never *perceptibly* reach great distances from their origin. Hence they do not develop the large, slow earth-waves which set quiet bodies of water into slow oscillation or produce gentle swaying of trees or high buildings. Throughout the region in which a slight shock is felt the movements are rather rapid vibrations of small amplitude. They are perceived either by the senses as a trembling of greater or less vigor, or else by the rattling of doors, windows, crockery, furniture, or—when the movement is a trifle stronger—by the ringing of old-fashioned house-bells, the quivering of the leaves of trees and shrubbery, or even the ringing of church-bells and the overturning of tall, slender objects such as vases. Short pendulum-like objects such as chandeliers may be set in motion, and ordinary pendulum clocks may be stopped or disturbed; but long pendulums, such as trees and tall buildings, though made to *quiver,* do not *sway.* The strongest weak shocks occasionally produce alarm among timid or nervous people, and sometimes cause cases of nausea.

The essential difference, then, between the intensity of weak shocks and the low intensity of strong ones is in the *time of swing,* or period, of the earth motion: long in the marginal area in which a great shock is just barely perceived, and short in the epicentral tract of the weak shock. Strictly, no hard and fast line can be drawn separating strong shocks from weak; but in practice it is convenient and easy to classify them in this way.

(*d*) SOUNDS ACCOMPANYING EARTHQUAKES.

Sounds of low pitch are associated with the occurrence of earthquakes, quite apart from the creaking, crashing and groaning noises given forth by structures during the shaking. These sounds seem always to come from the ground. Sometimes they are so faint that they are barely audible,—just a low, grave, roaring noise—and again so loud that they have been likened to thunder or a distant cannonade. Some sounds are long drawn out, others short, like a muffled explosion. These noises are considered to be due to waves set up in the air by action of the most rapid rock vibrations.

These noises are heard both on land and at sea, preceding, accompanying and following earthquakes. In most cases they arrive just before the shock.

The intensity of the sound is not definitely related to the energy of the shock. In some great earthquakes they have not been heard at all: while the noises which accompany quite ordinary shocks may be loud and distinct, occasionally alarming. Such earth noises are very often heard without any accompanying shock. Nevertheless, their invesigation is of practical importance, for in some earthquake countries, and particularly in the case of certain shocks, noises are heard at frequent intervals for several hours or days preceding earthquakes. Hence there is the possibility that these may give warning of an acute state of elastic strain, especially if careful attention is given to the differentiation of the different sorts of sounds noted. Microphones have been employed in the study of these premonitory noises, with some promise of future success, but with no substantial accomplishment thus far.

When contemporaneous with a felt shock the sounds are heard throughout an oval area also affected by ordinary intensity phenomena.

This sound area usually has its long direction superimposed on the long axis of the intensity area, and thus affords a useful check on the determination of the position of the focus by the isoseismal and coseismal methods.

The following scale has been proposed by J. Knett as a common distinction of the force of the detonations.

I Degree. Detonation of the *very smallest* force; only dimly audible amid the greatest quiet and by laying the ear upon the ground.

II Degree. Detonation of *small* force; amid the greatest quiet and absence of wind distinctly audible in the air; more distinctly by listening on the ground.

III Degree. Detonation of *medium* force; a noise distinctly audible in the open air even without complete quiet; distinctly audible in a quiet closed room.

IV Degree. Detonation of *great* force; strong, terrifying noise.

V Degree. Detonation of the *greatest* force; violent, thunder-like cracking; similar to the report of not far distant firearms; general terror among the population.

Just as in the case of the intensity phenomena, it is probable that a description of the sound heard will serve better than the use of this scale, which nevertheless has value as a guide.

In order to establish identities among earthquake sounds reported by independent observers at different localities, their times of occurrence and their duration should be noted with sufficient accuracy —(giving the nearest minute, with the possible error of the determination, see page 54, and when it is possible to give the times correctly to the nearest second this should be done, since it will afford a refined delineation of the isacoustic lines, adding definiteness to the determination of the source of the sounds).

(*e*) SENSATIONS AND EMOTIONS OCCASIONED BY EARTHQUAKES.

Earthquakes have pronounced effect upon the sensations and emotions of men, and apparently of the higher species of the brute creation as well—apart wholly from the sensation of trembling or vibratory motion or unusual sounds. These feelings, to use the most general term for them, may be grouped in two classes.

In the first class are faintness, dizziness, nausea, fear in varying degrees, and all analogous feelings which can be ascribed directly to the unusual disturbances of equilibrium caused by the shock, or to apprehension of danger from its behavior. The causes of these are in part objective and due to the earth motion, and in part subjective, the motor effects of cognitions arising from experience and intuition. Feelings of this sort accompany or follow the shock, are experienced generally, and are undoubtedly effects of its motion, subjectively modified.

In the second class are such manifestations as nervous irritability, restlessness among brutes and birds, ill-defined dread, a sense of oppression, and the like. Animals exhibit more sensitiveness in this respect than men. These feelings *precede* the shock by minutes, hours or even days, according to the reports upon numerous earthquakes. There is, of course, question as to whether such manifestations have objective seismic causes. It is always possible that they are coincidences—witness how often such periods of nervous tension are experienced by individuals without culminating in an earthquake. But they are reported too often, in too great a percentage of felt shocks, to be neglected altogether or to be rejected contemptuously as superstitions. For it is also possible that they have an objective basis in the physical conditions which prevail just before the shock. Davison, in his "A Study of Recent Earthquakes," says of the Riviera earthquake of 1887: "During the night of February 22-23, nervous persons in many towns and villages were agitated without apparent reason. Birds and animals, more sensitive than human beings to faint tremors, were more distinctly affected, especially for some minutes before the shock. Horses refused food, were restless, or tried to escape from their stables; dogs howled, birds flew about and uttered cries of alarm. As these symptoms were noticed at more than one hundred and thirty places within the Italian part of the central area, there can be little doubt that they were caused by microseismic movements, for the most part insensible to man."

Similar phenomena were less generally observed in the California earthquake of 1906.

Since even a few seconds' warning might often save countless lives and take from an earthquake its threat of disaster, even such intangible precursors as these are worthy of careful attention. Since effects of this sort are not susceptible of classification, observers should report them by giving brief descriptions.

(*f*) UNCLASSIFIED PHENOMENA.

The more common things associated with the occurrence of earthquakes, both great and small, have now been treated in some detail. The value of such knowledge has been indicated. However, *any observed phenomena not comprised in the foregoing groups* are perhaps of *still greater scientific importance,* because uncommon and sporadic, and hence rarely subjected to observation, criticism, and interpretation. For example, lights and fire or flame effects are reported in the case of a considerable number of shocks all along from the Lisbon earthquake to that in California in 1906,—but too infrequently and by too few persons for the probability of subjective influence to be overborne. A full description should always be given of all effects of this kind reliably observed.

APPENDIX.

For convenience of reference and guidance in making records of observations, a tabular outline of the facts and phenomena to be looked for and noted, which have been treated of in detail in the foregoing pages, is appended here.

SCHEME FOR OBSERVATIONS ON EARTHQUAKES.

Name of Observer,

(*a*) Locality and whereabouts of observer:

State,

County,

City or town,

Part of town. Give location at time of shock as precisely as possible, stating whether outdoors or within and upon what floor or story of the building.

How occupied at instant of shock.

(*b*) Time of occurrence, of each shock and each distinguishable phase.

Year,

Month,

Day of month,

Hour (a.m. or p.m.),

Minute, as accurately as possible. (See page 54.)

Second. Never give the second unless accurately. (See page 54.)

State the number of shocks.

Time of *duration* of each.

(*c*) Intensity of the shocks—phenomena depending upon the energy.

High Intensity—Strong effects of great earthquakes.

Hurling of objects into the air free of their resting places. (See pages 65-66.)

Distortion of the surface—disturbance of lines of sight and levels. (See pages 67-70.)

Surface fault phenomena—traces, scarps and rock fissures. (See pages 70-71.)

Surface changes in loose earth—landslides, earth-slumps, earth-flows, earth-avalanches, fissures in earth. (See pages 72-73.)

Effects upon underground water.

Craterlets.

Changes in drainage.

Changes in springs and wells. (See pages 73-74.)

Effects in forests.

Effects along sea coasts.

Low Intensity—Effects of *strong* shocks. (See pages 76-77.)

Dizziness and nausea.

Long-period swinging movements affecting trees, doors, tall buildings, etc.

Rhythmic surges or waves in quiet bodies of water or of any fluids in small basins.

Low Intensity—Effects of *weak* shocks. (See page 77.)

Sensation of trembling, jarring or twisting.

Rattling of doors, windows, crockery, furniture.

Quivering of trees and shrubs.

Ringing of church bells.

Toppling of vases, etc.

(*d*) Sounds accompanying earthquakes.

Statement of occurrence and character of sounds.

Time of occurrence and duration. (See also under (*b*) and pages 78-79.)

(*e*) Sensations and emotions caused by earthquakes.

I. Those which accompany the shock or follow it immediately; nausea, dizziness, fear, etc. (See pages 79-80.)

II. Those which precede the shocks; being general nervous disturbances.

(*f*) All phenomena not classified.